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PRINCIPAL INVESTIGATOR: Eliezer Peli, Ph.D.
Alexandra Bowers

CONTRACTING ORGANIZATION: Schepens Eye Research Institute
Boston, MA 02114

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13. SUPPLEMENTARY NOTES

14. ABSTRACT The overall aim is to conduct preliminary evaluations of new rehabilitation strategies and new functional assessment methods for homonymous hemianopia (HH) and spatial neglect (SN), disabling visual and cognitive perception conditions that commonly occur as a result of severe traumatic brain injury (TBI) and stroke. Both HH and SN prevent detection of objects on the affected side, resulting in unsafe walking and driving. Using realistic tasks in virtual environments representative of everyday mobility challenges we are evaluating a novel optical device – expansion prism (EP) glasses - combined with a new computerized perceptual-motor training regimen in helping people with HH and SN detect and avoid obstacles on the affected side. In the first year we have made good progress in developing the training software and preparing the functional assessments, and have started recruitment. Specifically, we (1) obtained all necessary IRB approvals; (2) made excellent progress in developing and testing the training program and training task suite; (3) made excellent progress in preparing the functional assessments in the driving simulator and virtual mall that will be used to evaluate performance without and without the prism glasses before and after training; (4) evaluated mobile eye tracking technologies that will be used for an outdoor walking task; (5) began recruitment; (6) collected pre-pilot data from participants who did not meet the study criteria, and (7) enrolled 3 participants for the main pilot study. Results from the first participant who has completed the protocol are promising showing significantly improved detection rates and collision judgments with the EP-glasses after training.

15. SUBJECT TERMS
Hemianopia; spatial neglect; prismatic corrections; adaptation; perceptual-motor training; rehabilitation; mobility; functional outcome measures

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Table of Contents

INTRODUCTION

Rehabilitation of Visual and Perceptual Dysfunction after Severe Traumatic Brain Injury
The aim of our project is to conduct preliminary evaluations of new rehabilitation strategies and new functional assessment methods for homonymous hemianopia (HH) and spatial neglect (SN), disabling visual and cognitive perception conditions that commonly occur as a result of severe traumatic brain injury (TBI) and stroke. Both HH and SN prevent detection of objects on the affected side, resulting in unsafe walking and driving. In our pilot study we are evaluating a novel optical device combined with a new computerized perceptual-motor training regimen in helping people with HH and SN detect and avoid obstacles on the affected side. The optical device, expansion prism (EP) glasses, uses high power prism segments embedded in a regular spectacle lens to project areas from the affected (blind/neglected) side onto the unaffected (seeing) side while leaving central vision uninterrupted. The purpose of the perceptual-motor training is to help people learn how to interpret the information from the peripheral prisms so that they can correctly identify the location of objects detected via the prisms and respond appropriately (e.g., avoid a collision when walking or turn to face a person approaching on the blind/neglected side). The effects of the EP glasses and training is being evaluated using realistic tasks representative of everyday mobility challenges including detection of pedestrian hazards in a driving simulator and obstacle collision judgments in a virtual mall. In addition, this project addresses another important basic research question; namely, the effect of the interventions on eye movement behaviors. Eye movements are being measured without and with EP glasses and after training in the driving simulator, the collision judgment task and a natural walking task. The eye movement data will provide a basic understanding of how participants are using the device and will help guide future developments of prismatic devices for HH and SN.

BODY

In our approved Statement of Work, tasks 1-4 were to be carried out in the first year of the grant, and task 5 was expected to be started toward the end of the first year. Each of these tasks is reported below. Tasks 6 and 7 were allocated to year 2 and are therefore not discussed.

I. Task 1 - Preparation of study protocols.

This task is complete.

Accomplishments

- All necessary local IRB and USAMRMC approvals have been obtained.
- All experimental protocols and associated study paperwork including data forms and questionnaires have been prepared

II. Task 2 - Complete development of the perceptual-motor training program

We have made excellent progress on this aspect of the project. At the start of the year we had a very rudimentary version of the program that was very slow, had many "bugs" and had very limited capabilities. Through intensive programming and testing efforts, we now have a program that is much more user-friendly, has the majority of the capabilities needed for the pilot study (Task 5), and has been pilot-tested with a number of patients. The training involves, while wearing the prism glasses, reaching out and touching (on a touch screen) peripheral objects displayed on the blind/neglected side and on the seeing side of the visual field while maintaining fixation on a central target

Accomplishments – Development of the program and training tasks

- We have released and tested 24 revisions of the program, starting out at revision 4.10 (at the start of the grant period) and currently working on version 5.21. The main improvements in the program include:
    - Graphical input and editing of 6 independent test zones (Figure 1a), with improved user interface.

- Definitions of complex tasks (described below)
    - Improvements to the backup and data safety features of the program, including database cleanups, touch-by-touch output of respond records, and automatic backups of the data files at the beginning and end of sessions.
    - Improvements to the practice training module. Subjects can now receive formal instruction while touching targets on image, and video backgrounds while fixating on small images or videos.
    - Addition of automated audio feedback (to indicate whether or not the touch was accurate) and a summary at the end of a session.
    - Improvements to program timing, including removal of jittery target motions, the addition of a pause button, more accurate measurements of reaction time, and fine tuning of background image cycling.
    - Increased ability to map the subject's visual field quickly and flexibly.

- We have developed a data analysis program to support the above changes in the training program, providing
    - Summary statistics and graphs for touch accuracy, reaction times and total time spent in training
    - Summaries that show changes in performance for each participant as a function of task difficulty level and session number

- We have developed a range of tasks including easy reach-and-touch exercises (simple targets on image and video backgrounds), to more complex reach-and-touch tasks with increased attentional load representative of real-world use of the prism glasses (these aspects are particularly important for studying patients with SN):
    - Performing a "stop-go" task (only reaching to touch peripheral targets when the central target is green; withholding touches when the central target is red).
    - Movie watching during training.
    - Reporting hazards in background videos of driving scenes while simultaneously performing the reach-and-touch task.

- We have developed and refined a training protocol with 6 levels of task difficulty ready for implementation in the pilot study (Task 5)

- We have upgraded our test environment including purchase of a new (faster) computer and large touch screen (Figure 1b), and are currently in the process of purchasing a new motorized table and chair to ensure that the prism-training environment is as comfortable as possible for patients in the lengthy pilot study.

- We have developed a detailed manual documenting how to use the prism-training program and run training sessions.

- Pre-pilot testing of the training program and training tasks was completed with individuals with incomplete HH who did not meet the criteria for the main pilot study.

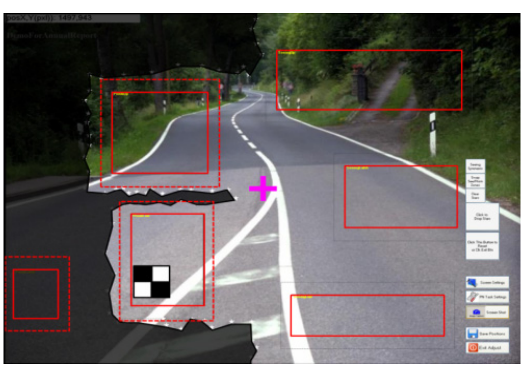


Figure 1a. Operator's screen showing the latest version of the perimetry and training/test zone placement function for a patient with left HH. The operator is able to map the prism-expanded area using the same background and stimulus that will be used for training. Gray transparent overlay has been used to highlight the remaining area of (non-expanded) visual field loss in the left hemifield.

The test zones (boxes in red) can now be easily adjusted using a click and draw function. In the left hemifield, there is a training/test zone in the upper prism zone, lower prism zone, and one in the blind area of the field where we do not expect any targets to be detected.

Figure 1b. Participant Training Station. The participant is seated in front the newly installed wide-screen touch screen monitor. The operator's screens are on the monitors to the left. A small webcam is used to monitor fixation.

Figure 1c. Black-and-white checkerboard targets are presented in one the six test zones (fig. 1a, not visible to the participant). The subject is instructed to fixate the central pink cross and reach out to touch the target, which in this case has been presented in a prism zone for a patient with left HH. The subject detects the target but incorrectly points far to the right of its location. This is the expected behavior at baseline for participants with left HH wearing EP glasses.

III. Task 3 – Functional assessments in the driving simulator and virtual mall

We have made much progress in preparing the functional assessments in the driving simulator and virtual mall, and have already implemented both in the pilot study (Task 5).

Accomplishments – Driving simulator

- We have adapted and tested prior scenarios and analysis programs for the evaluation of detection performance without and with EP glasses
- We have developed procedures for using the newly-acquired remote SmartEye head and eye tracking system in the simulator to record eye and head movements when driving with and without prism glasses so that we can determine how participants are using the EP glasses and the effects of perceptual-motor training on eye movement behaviors. Much effort has been devoted to the development and verification of the calibration of that system.
- We have also developed software to plot eye and head movements for specific segments of each drive, including around the time when pedestrians appear, on approach to intersections, and on other straight segments without pedestrian events, and have begun to develop software to quantify eye and head movement behaviors.
- Pre-pilot testing of the driving simulator scenarios and eye tracking has been conducted using individuals who did not meet the criteria for the main pilot study.

Accomplishments – Virtual mall collision judgment task

- We have adapted and tested a collision judgment task and analysis program so that it is suitable for the purposes of this project. This includes developing obstacles of different sizes, the addition of "catch trials" (trials without an obstacle), the ability to collect reaction time data as well as collision judgment data.
- We have evaluated several options for recording eye movement behaviors while performing the collision judgment task so that we can determine how participants are using the EP glasses and the effects of perceptual-motor training on eye movement behaviors. For example, whether participants can make collision judgments on the blind/neglected side using the prism image alone (i.e., without foveating the collision object)
- We have begun integrating eye tracking recording into the collision judgment task, but have not yet collected data with HH subjects.
- Pre-pilot testing of the virtual mall scenarios has been conducted using individuals who did not meet the criteria for the main pilot study.

IV. Task 4 - Outdoor walking task

Eye and head movements will be recorded while patients walk a short outdoor route (or complete the route in their wheelchair). Here we are interested in eye and head movement behaviors in a natural task, which may differ from those recorded in the virtual environments, and whether the behaviors change when using EP glasses and after training.

Accomplishments

- We developed a collaboration with Dr Jeff Pelz from Rochester Institute of Technology who has extensive experience in using mobile eye-trackers in natural outdoor environments and will support analysis of the data we collect.
- Dr Pelz loaned a mobile eye tracker to us for two weeks and provided training in the use of that tracker. As the output of the tracker is registered on distorted scene images, we have developed a new calibration procedure for obtaining accurate saccade data.
- We have obtained a quote for the purchase of a similar eye-tracker and plan to purchase one within the next month.
- We have conducted extensive evaluations on a novel outdoor head-tracking method for monitoring head position during the outdoor walking task. After testing inertial sensors from two companies (Trivisio and Vectornav), we have determined that the Vectornav sensor can meet our requirements.

V. Task 5- Pilot study EP glasses and training

As we received USMARC approval during the third quarter, we were, therefore, able to start recruitment and screening ahead of schedule. The aim is to have 12 patients with HH without SN and 12 patients with HH with SN complete the pilot study. Allowing for attrition, we expect to enroll 15 in each group, but we will screen more than this as some will not meet the study criteria.

Accomplishments

- Five individuals with HH without SN have been screened for the main pilot study of which 2 met the criteria and have been enrolled in the study; 1 has completed the protocol (14 visits) and 1 is currently lost to follow up (we are trying to contact him).
- Three individuals with HH with SN have been screened of which 1 met the criteria and has been enrolled and is part way through the study.

Preliminary data

As the main pilot study has only just started we report individual data for the one participant (S1) who has completed the protocol: an 18-year old male with left HH without SN, who has had HH for 2 years as a result of an arteriovenous malformation that required surgery.

A. Perceptual Motor Training

S1 advanced through the entire 6 levels of perceptual motor training in 176 minutes of on-task "run time" accumulated over seven 90-minute visits (approximately 2 visits per week for 4 weeks). The median on-task run time for each visit was 26 minutes (range 12-33 min.), with the other time dedicated to set-up, rest breaks, and discussion. Data were collected for each task, in addition to a "standard" task run twice at each visit to enable comparisons of within-visit and between-visit performance.

At the beginning of training, touches to targets presented in the prism zone (Figure 2, upper panel, black line) were inaccurate by an amount equal to the displacement of the prism (i.e. about 30° to the right of the real position). As training progressed and S1 learnt to use visual feedback to guide his finger to touch the real position of the target in the prism zone, touch accuracy improved until it was as good as the accuracy of touch to targets in the seeing hemifield (Figure 2, upper panel, gray dashed line). When first using visual feedback, reaction times for touching targets in the prism zone increased (Figure 2, lower panel, black line, visits 1a and 1b) and then gradually decreased over subsequent visits until reaction times were similar for touches in the prism zone and the seeing hemifield. By visit 6, these improvements in touch accuracy and reaction times to targets presented in the prism zone were sustainable (between visits).

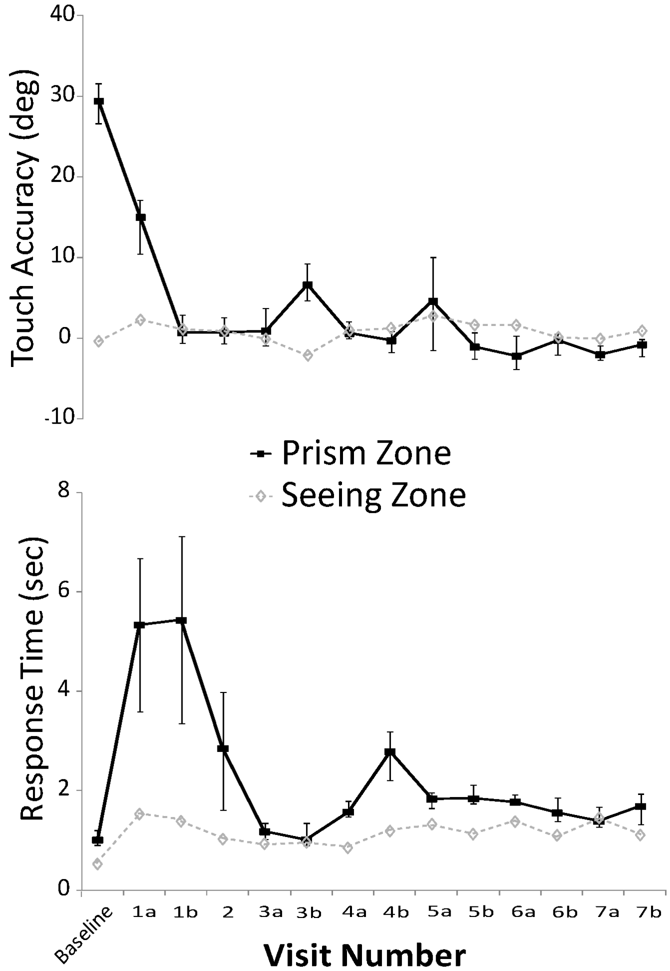
Figure 2: Median touch accuracy (**upper panel**) and response times (**lower panel**) for S1 over the course of 4 weeks of training. The same task was used at baseline (before any training), and at the beginning and end of each of seven training visits (subscripts a, and b, respectively).

Touch accuracy represents the median horizontal distance in degrees of the subject's touch from the actual position of the target. Positive values represent a touch to the right of the actual position and negative to the left; a perfectly accurate touch would be 0.

The black squares joined by the black line represent the response time and touch accuracy for targets that appeared in the prism zone in the participant's blind hemifield. The open grey diamonds joined by the dashed grey line represent the response time and touch accuracy for targets appearing in the seeing zone in the normal vision

In the prism zone, accuracy of touch and response times improved rapidly with training. By visit 6, touch performance was as accurate and quick to targets in the prism zone as in the seeing zone. (See text for further comments)

Error bars represent the interquartile range.



B. Driving simulator

Each driving simulator assessment comprises five test drives (each about 10 minutes) on pre-determined routes guided by computer-generated, spoken navigation cues (similar to GPS instructions). While driving, the participant's primary task is to press the horn button whenever he/she detects a pedestrian figure that appears periodically at small and large eccentricities on the right and left of the roadway. The pedestrian figures move with biological motion toward the road on a collision course, but do not enter the travel lane. The driving is highly engaging as there is other traffic on the roads and the participants have to obey all the normal rules of the road. Main outcome measures are detection rates and reaction times.

S1 demonstrated marked improvements in blind side detection rates and reaction times when driving in the simulator with EP glasses after training compared to without the EP glasses before training (Figure 3). In particular, detection rates for pedestrians at large eccentricities on the blindside (outside the usual scanning area of S1 but within the visual field expansion range of the EP glasses) improved from 38% to 100% and the median blind side reaction time improved from 5 s to 1 s. These detection rates and reaction times were as good as those on the seeing side (100% and 1 s). Most encouraging is that we were able to collect gaze tracking data which shows detection of blind side pedestrians *without scanning*, strongly suggesting the prism-expanded vision was utilized (Figure 3).

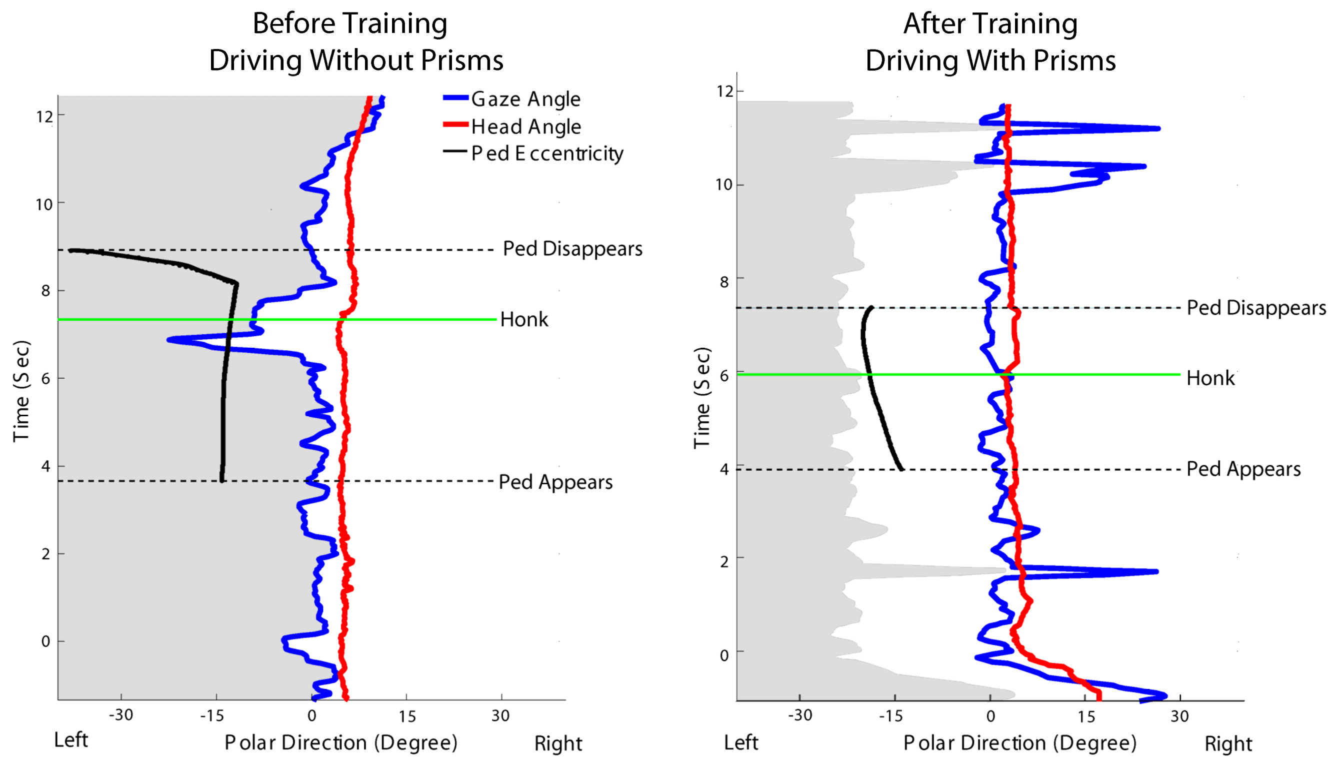


Figure 3: Gaze data for S1 recorded in the driving simulator without EP-glasses before training (left panel) and with EP-glasses after training (right panel) for pedestrians that appeared at about 15° in the blind left hemifield (the time of pedestrian appearance and disappearance are marked with dashed lines). In general, S1 showed relatively little scanning toward the blind left side.

Left panel: Without the EP glasses, the pedestrian in the blind left hemifield (thick black line) is not detected until there is a large leftward scan which brings the gaze (blue line) to the eccentricity of the pedestrian; detection is indicated by a horn press (green line) shortly after the large scan.

Right panel: With the EP glasses, another pedestrian, also in the blind left hemifield but within the range of the visual field expansion, is detected without any large leftward scans; this strongly suggests that it was detected from the prism-expanded vision. Note also in the right panel that there are more scanning movements to the right than to the left (blind) hemifield

The area of visual field loss is indicated by grey shading. In the right panel, the visual field expansion of the EP glasses extends about 25° laterally into the blind left field; hence the grey shading is offset from the gaze position by about this amount.

C. Collision judgments in virtual mall walking simulator

The virtual mall is a virtual reality model of a real shopping mall (Figure 4). Participants sit or stand at 1m in front of a large rear-projection screen on which the shopping mall is displayed. Their task is to report whether they would collide with stationary obstacles (life-sized human figures; Figure 4) that periodically appear at different offsets (up to 120cm to each side) from the simulated participant's walking direction. Outcome measures are detection rates for obstacles, the perceived safe passing distance (collision envelope) on the blind and seeing sides, and judgment uncertainty.

Even before training, the immediate application of the EP-glasses improved S1's blind-side detection from 23/44 (52%) to 44/44 (100%). However, every appearance of the figure on the blind side was judged a collision, irrespective of the magnitude of the offset, suggesting misinterpretation of the prism-expanded vision (Figure 5a). After training, blind-side collision judgments with the EP glasses were more similar to those on the seeing side, suggesting better interpretation and use of the expanded vision from the prisms (Figure 5b).

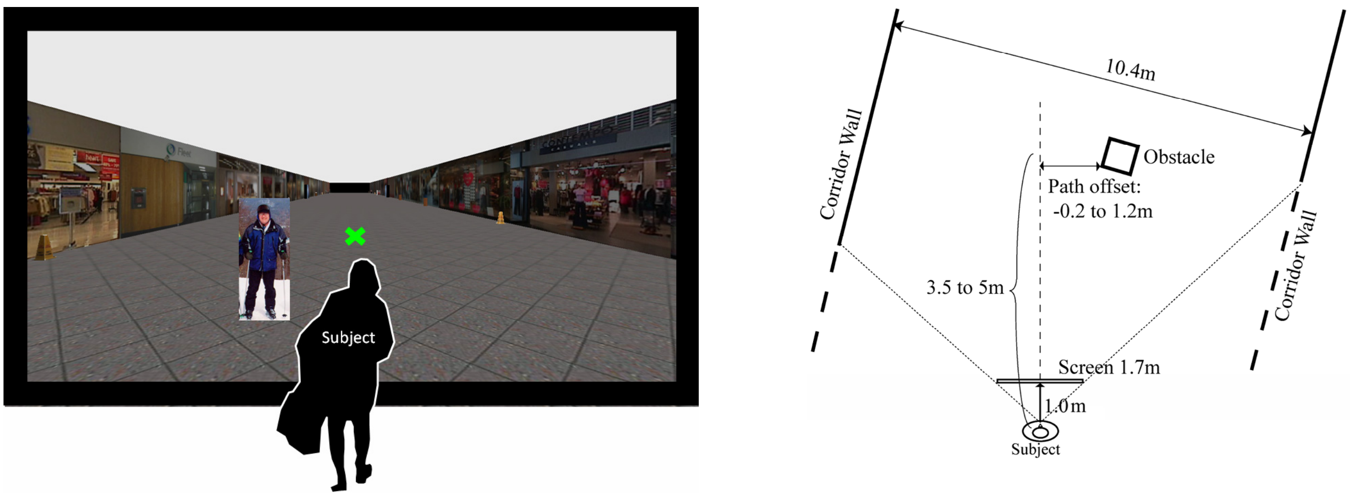


Figure 4. Illustration of the virtual reality mall set-up and collision judgment task.
Participants are instructed to fixate a cross at the center of the screen (green x) and imagine that they are walking in a real shopping mall. A figure appears, moves in a linear path, and disappears after 1 second. The participant clicks a button when they detect the figure and then responds verbally "collision", "no collision", or "nothing" for each trial. The figure may appear at any eccentricity offset to the right or left of center, or not at all (10% of trials). This is repeated for a total of 88 trials. To determine the perceived safe passing distance (collision envelope), a psychometric function is fit to the data (Figure 5).

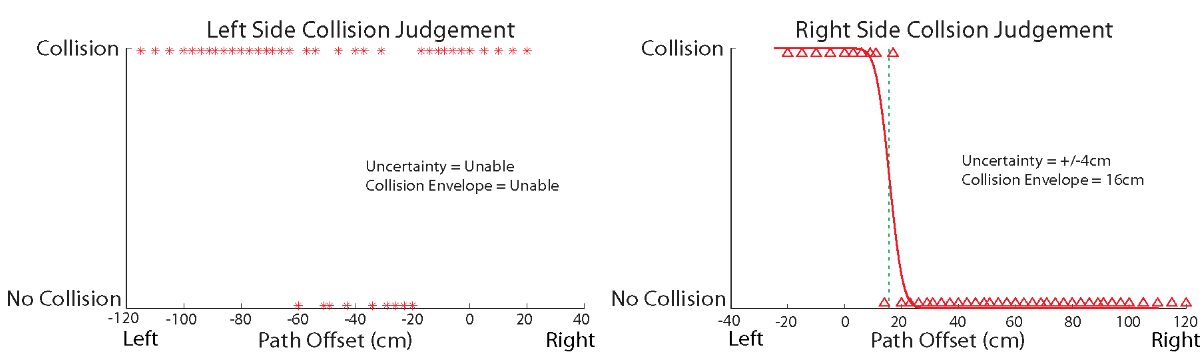


Figure 5a: Collision judgments with EP glasses **before** training. The x-axis is eccentricity (cm) with 0cm being the center of the patient's body. The right (seeing-side) collision envelope is 16cm (rightmost graph) with little uncertainty (SD = 4cm). On the left, prism-expanded side, detection rate was 100%, but every appearance of the human figure was called a collision, suggesting an inability to correctly interpret the spatial location of the figure from the prism-expanded vision

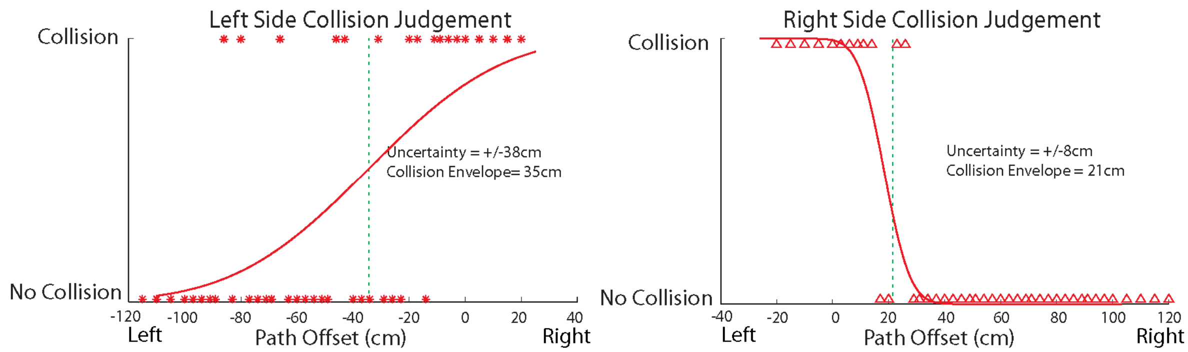


Figure 5b: Collision judgments with EP glasses **after** training. The left-side collision envelope of 38cm from the prism vision is approaching that of the seeing side (21cm), but the uncertainty is much higher (SD 38cm and 8 cm, respectively). Nevertheless, collision judgments from the prism-expanded vision are much improved relative to the pre-training measurement, suggesting a positive effect of the training on interpreting and using the prism-expanded vision.

KEY RESEARCH ACCOMPLISHMENTS

In this first 12 months, we have:

- Obtained all necessary IRB approvals;
- Made excellent progress in developing and testing the training program and training task suite;
- Made much progress in preparing the functional assessments in the driving simulator and virtual mall that will be used to evaluate performance without and without the prism glasses before and after training;
- Evaluated mobile eye- and head-tracking technologies that will be used for the outdoor walking task;
- Begun recruitment;
- Collected pre-pilot data from participants who did not meet the study criteria;
- Enrolled 3 participants for the main pilot study.

Results from the first participant who has completed the protocol are promising showing significantly improved detection rates and collision judgments with the EP-glasses after training.

REPORTABLE OUTCOMES

This first year was primarily devoted to development work and the pilot study has only just started. Therefore, at this point in time, there are no reportable outcomes such as manuscripts, abstracts or presentations. However, we anticipate having sufficient data to be able to submit abstracts within the next six months.

CONCLUSIONS

In this first year we have made excellent progress in the development aspects of the project and have already begun recruitment for the pilot study. Results from the first participant to complete the protocol are promising suggesting that the EP glasses improved blindside detection performance (evaluated in the driving simulator) while the perceptual-motor training improved the ability to use the prism-expanded vision to determine the correct spatial location of objects in the blind hemifield and make accurate collision judgments (in the virtual mall walking simulator).

REFERENCES

None

APPENDICES

None